NMAB-246
FEBRUARY 1970

# An Approach for Systematic Evaluation of Materials for Structural Application

A Report of the

**NMAB** NATIONAL MATERIALS ADVISORY BOARD

[redacted]



NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES–NATIONAL ACADEMY OF ENGINEERING

# NATIONAL MATERIALS ADVISORY BOARD

## DIVISION OF ENGINEERING - NATIONAL RESEARCH COUNCIL



(3/70)

# AN APPROACH FOR SYSTEMATIC EVALUATION OF MATERIALS FOR STRUCTURAL APPLICATION

Prepared by

THE COMMITTEE ON MATERIALS EVALUATION TECHNIQUES

NATIONAL MATERIALS ADVISORY BOARD
Division of Engineering - National Research Council

Publication NMAB-246

National Research Council

National Academy of Sciences-National Academy of Engineering

Washington, D. C.

February 1970

This report is one of a series of studies undertaken by the National Materials Advisory Board* for the National Academy of Sciences and the National Academy of Engineering in partial execution of work under Contract No. DA-49-083 OSA-3131 with the Department of Defense.

As a part of the National Research Council, the National Materials Advisory Board performs study, evaluation, or advisory functions through groups composed of individuals selected from academic, governmental, and industrial sources for their competence and interest in the subject under consideration. Members of these groups serve as individuals contributing their personal knowledge and judgments and not as representatives of any organization in which they are employed or with which they may be associated.

The quantitative data published in this report are intended only to illustrate the scope and substance of information considered in the study, and should not be used for any other purpose, such as in specifications or in design, unless so stated.



*The "National Materials Advisory Board" was known as the "Materials Advisory Board" prior to 1969.

For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151. Price $3.00 (Paper), $0.65 (Microfiche).

NATIONAL MATERIALS ADVISORY BOARD

COMMITTEE ON MATERIALS EVALUATION TECHNIQUES

Chairman: Mr. D. B. King, Vice President, Product Development, Brush Beryllium Company, 17876 St. Clair Avenue, Cleveland Ohio 44110.

Members: Mr. John Arnquist, Military Airplane Systems Division, The Boeing Company, P. O. Box 3999, Seattle, Washington 98124.

Dr. Herbert Becker, Head, Structural Sciences Department, Mithras, Inc., 701 Concord Avenue, Cambridge, Massachusetts.

Professor Thomas J. Dolan, Head, Department of Theoretical and Applied Mechanics, College of Engineering, University of Illinois, Urbana, Illinois 61801.

Mr. L. F. Hrusovsky, Chief Metallurgist, North American Rockwell Corporation, 2445 West Maple Road, Birmingham, Michigan 480009.

Mr. Stanley A. LaFavor, Section Manager-Strength, Department 231, McDonnell Douglas Corporation, P. O. Box 516, St. Louis, Missouri 63166.

*Mr. Alan V. Levy, TRW Systems, 3565 "C" Street, Sacramento, California 95816.

Mr. Herbert Popp, Manager, Materials Evaluation Group, Flight Propulsion Division, General Electric Company, Cincinnati, Ohio 45215.

Dr. Vito L. Salerno, President, Applied Technology Associates, Inc., 29 Church Street, Ramsey, New Jersey 07446.

Mr. G. Alan Starr, Chief of Applied Research & Development, Vought Aeronautics Division, LTV Aerospace Corporation, P. O. Box 5907, Dallas, Texas 75222.

*Member until January 7, 1969.

Liaison Representatives:

Mr. John C. Barrett, ODDR&E, Office of Assistant Director for Chemical Technology, The Pentagon, Washington, D. C. 20301.

Mr. Bernie J. Cobb, Army Missile Command, AMSMI-RS, Redstone Arsenal, Huntsville, Alabama 35809.

Mr. J. M. Crowley, Office of Naval Research, Department of the Navy, Washington, D. C. 20390.

Mr. Norman Reed, Army Materials & Mechanics Research Center, Watertown, Massachusetts 02172.

Mr. D. A. Shinn, Air Force Materials Laboratory, Code MAAM, Wright-Patterson Air Force Base, Ohio 45433.

National Materials Advisory Board Staff:

Dr. Joseph R. Lane, Staff Metallurgist, National Materials Advisory Board, National Research Council, 2101 Constitution Avenue, N. W., Washington, D. C. 20418.

TABLE OF CONTENTS

## ABSTRACT

An approach is discussed which will enable the Services, the producers, and materials engineers to decide upon the material evaluation tests which need to be performed for purposes of obtaining screening, selection, and design data. The necessary tests are indicated by a system which takes into account the system, vehicle, component, environment, and operational criteria. The system is based upon the preparation of a large number of applications case histories, the data from which must be recorded according to a rigid format. The compilation of case histories makes up what is called the Applications Analysis Data Bank. The system can be coded so that the case history data can be computer-analyzed to answer a number of pertinent questions for which answers are not easily obtainable at present. A complete materials evaluation system will consist of three data banks: (1) Applications Analysis, (2) Material Properties (these now exist), and (3) Material Evaluation Techniques. Examples are shown to demonstrate the workings of the proposed system and the many types of questions which can be answered. The necessary steps for the further development of the system are recommended.

## INTRODUCTION

The present system by which the need for property data is forseen, the data supplied, and used, has become seriously inefficient. Because there is no systematic materials evaluation conducted:

1. The period of time between development and utilization of new materials is excessive.
2. The critical attributes of new materials are often overlooked.
3. The critical attributes of established materials are sometimes overlooked when applied in new design situations.
4. The optimum material which best meets the performance, fabrication and cost parameters may not be selected.

The Air Force Materials Laboratory was one of the groups that recognized early the growing seriousness of the problem. One manifestation was the difficulty in selecting those materials which warranted inclusion in their data acquisition program, and in determining which properties to measure. Those who produce materials, and designers who specify the materials have related problems.

The formation of the Committee at the suggestion of the Department of Defense was an attempt to explore the nature and ramifications of the general problem and to recommend an approach for its solution.

Materials engineers are continually confronted with the need to decide how materials should be evaluated. At other times, they are asked to dec. the usefulness of a new test or of a variation of an old test. The only way these and other related questions can be answered is to have an intimate knowledge of the way the materials in question must perform in the application of concern.

In addition, the timing to be employed in developing the required data is critical. If data are developed in great detail for specific materials too far in advance of projected applications, the risk of wasted effort is great. On the other hand, a new weapon application cannot use a new material unless sufficient data are in hand at the time of design. This presents a dilemma to those charged with advancing the state-of-the-art for national defense. The problem is twofold:

1. Information is not readily available about how a new material may be employed to take advantage of its physical and mechanical properties in the context of the operating environment. Similarly, how best to evaluate the new material may not be appreciated.
2. Present guidelines are inadequate for defining the depth of evaluation (assessment of suitability) for a new material in advance of a specific end application.

The Committee recognized, after considerable deliberation, that the procedure by which designers utilize materials data is not generally understood. A formalizing of what is frequently an intuitive process is presented in Chapter I. This is considered to be one of the significant contributions of the Committee.

With an appreciation of the sequential nature of the decisions involved in selecting and incorporating a material into a design, the nature of the overall problem was clarified. The user of the data, the provider of the data, and the producer of the material have different interests and concerns.

The user is defined as one of the following: the designer, the materials engineer who assists the designer in deciding what data to use or obtain, and who has the problem of deciding what materials to test, tests to develop, and how to evaluate the results, or the materials producer who needs to know what to develop.

In the design process, specific requirements for materials data will become clear only following definition of the component, and the way in which it is to be fabricated and used. In this report, the discussion of the design process is confined to aerospace applications, but in general, it is applicable in a much broader sense.

Studies to identify more efficient ways to carry out missions, such as warhead delivery and bomber interception, result in a reasonably quantitative set of conditions such as speed, range, payload, type of round, and delivery system, etc. When these boundaries have been set, the next step is to develop a conceptual design. At this point, the iterative process of making trade-offs between an ideal design and reality is started. The first concept may be found to be impractical because the materials or data are not available. Compromises must be made and a second design attempted. Again, it may be found that the requirements cannot be met unless new materials or new data become available. Finally, after a process that varies in length depending on the complexity of the requirement, a system design is established and a component designed, manufactured, and tested. In the event of component failure, an analysis may show that the operating conditions were not predicted properly or that a material property was not well enough known. Appropriate changes will be made and finally the component will be accepted. It may then fail in service. The service failure may occur for the same reasons as the test failure, or it may fail for entirely different reasons that reflect an inadequacy of laboratory tests to simulate service conditions.

The materials engineer must anticipate the needs of the designer described in preceding paragraphs. If a material is not characterized in such a way that it can be considered for future designs, an avenue of progress will be closed; thus, all new materials and evaluation technique combinations must be constantly studied. Because of the large number of materials and evaluation

techniques, it is mandatory that some system of selection for action is available. At present, there are many diverse systems, each influenced by the special requirements of the laboratory or individual concerned with the problem. As a consequence, some testing may be completely overdone and other requirements for evaluation may be omitted entirely.

There is a community of interest on the part of all these groups, but communications have been poor—occasionally nonexistent. The cause of poor communication has been the lack of understanding of the way in which property data are utilized (understanding of the nature of the decisions involved in the separate steps in materials selection and in design), and the lack of any coherent system which would enable any group to obtain what they needed in terms of end item parameters, material properties, or design considerations.

What was sought was some common ground on which a unified system could be constructed. The following sections of this report describe the system which evolved. Feasibility has been demonstrated on a very limited scale, and more work is needed to refine and expand on the concept presented.

# I. THE MATERIAL EVALUATION PROCESS

## A. Material Applications and Related Environments

An analysis of current and projected material evaluation requirements and capabilities requires a means for classifying the total population of material applications. This is necessary if only to provide some perspective concerning the scope of the analysis attempted by the Committee.

All material applications may be classified in any of the following ways; each of which is of interest and concern to some producer or user of materials:

1. By major field;
2. By user;
3. By function;
4. By major environment.

These four considerations are illustrated in Table 1. Obviously, branching of each category can be extended to almost any desired degree.

The Committee restricted its investigation to structural load-bearing applications in an aerospace environment. Broadening the scope, for example, to include the vehicles and systems employed by the Army and the Navy, was considered to be a possible logical extension, involving more variables but not changing the basic concept.

These applications may be further classified as shown in Table 2. As before, additional branching of the systems and subsystems is possible.

The classification of Table 2 will permit the projection of gross application requirements, but they will not be sufficient for a detailed analysis of

## TABLE 1

## GENERAL CLASSIFICATIONS OF MATERIAL APPLICATIONS

1. Major Fields
   a. Transportation
   b. Power generation
   c. Petrochemical
   d. Electronic
   e. Ordnance
   f. Tools and machinery
   g. Bio-medical
   h. Other

2. Users
   a. Military
   b. Commercial
   c. Other

3. Functions
   a. Structural load-bearing
   b. Electromagnetic
   c. Chemical processing
   d. Other

4. Major Operational Environment
   a. Air and space
   b. Marine
   c. Over the ground
   d. Other

## TABLE 2

## CLASSIFICATIONS OF AEROSPACE LOAD-BEARING STRUCTURE APPLICATIONS

1. Aerospace Environment
   a. Subsonic
   b. Supersonic
   c. Hypersonic
   d. Space reentry
   e. Space

2. Vehicle or Equipment System
   a. Aircraft
   b. Missile
   c. Launch vehicle
   d. Space vehicle
   e. Ground support

3. Vehicle or Equipment Subsystem
   a. Airframe
   b. Powerplant
   c. Secondary power system
   d. Fuel system

specific material evaluation problems. This will require the identification of the fundamental "building block" structural components that comprise the subsystems. Examples of these are shown in Table 3.

This listing is suggestive of those components where the functional requirements may differ widely, with the result that those material characteristics that are important for one component, may be secondary for some other component.

For a particular combination of vehicle system, subsystem, and component, the operational and design environment can be specified. This is essential to an analysis of the material evaluation requirements. This environment specification need not be explicitly detailed but must designate the range that is significant. An example of a possible environment classification system is shown in Table 4.

This classification system is similar in concept to that developed by the Materials Advisory Board Committee on Aerospace Manufacturing Requirements and presented in MAB report number 231.

A second level of classification can easily be provided, e.g., temperature ranges, cyclic ranges, time ranges, etc. Table 4 should be considered suggestive only and not a definitive classification system. At this point, the statistically minded reader may conclude that since the number of combinations of components shown in Table 4 is virtually limitless, any attempt to make a definitive analysis is hopeless and impractical.

It is this very complexity and enormity of specific combinations of applications and environments coupled with many potential materials that present the problem and the great need to find a workable approach to its solution. The computer-based approach, which will be described, can be developed to handle this complex problem. The approach proposed by the Committee rests on the following basic assumption:

## TABLE 3

## LOAD BEARING STRUCTURAL COMPONENTS

| | |
|---|---|
| Skin panels | Power transmission shafting |
| Pressure vessels | Compressor blades |
| Nose cone | Turbine blades |
| Leading edge | Heat exchanger |
| Spars, longerons | Heat shield |
| Major bulkheads and fittings | Armor plate |
| Optical transparency | Hydraulic tubing |
| Fasteners | Springs |
| Bearings | Gears |
| Hydraulic cylinders | Rocket nozzle |
| Wheels | Electromagnetic transparencies |
| Brakes | Control rods |
| Tires | Rocket nozzle vane |
| Propellers and rotors | |

## TABLE 4

## STRUCTURAL COMPONENT ENVIRONMENTS

**Loads**

- Static
- Dynamic
- Pressure
- Acoustic
- Impingement

**Duration**

- Time
- Number of cycles

**Thermal**

- Temperature
- Flux

**Radiation**

- Solar
- Cosmic
- Nuclear

**Chemical**

- Atmospheric
- Ozone
- Vacuum
- Saltwater
- Lubricants
- Hydrocarbon fuels
- Fuel oxidizers
- Combustion products
- Acids
- Hydraulic fluids
- Galvanic attack
- Interface effect

**Configuration**

- Component
- Size
- Shapes
- Weight envelopes

NOTE: Intervals of load, time, temperature, cycles, etc., may be assigned as desired.

THAT MATERIAL EVALUATION CRITERIA AND TEST TECHNIQUES MUST BE SUITED TO THE SPECIFIC APPLICATION AND ITS ENVIRONMENT. AND FURTHER, THAT A SYSTEMATIC RECORDING OF THE ENVIRONMENTAL DATA FOR SPECIFIC APPLICATIONS CAN BE DEVELOPED.

Table 5 is presented to illustrate the approach adopted by the Committee for recording application input data. The example illustrates the operational or design environment conditions that must be considered in the evaluation of materials for a pilot canopy on a supersonic aircraft.

Table 5 should be considered as a worksheet format for posting the relevant information. At this point in the discussion, the only column of interest is the column containing the "operational or design environment." For the component chosen as an example in Table 5, a more complete analysis would also present several other case histories for each of the several systems requiring pilot canopies. Thus, in addition to the system shown (Fighter Aircraft - Supersonic), other systems that pose similar functional requirements, i.e., optical windows, could be identified and their environments listed. For example, (1) subsonic tactical attack aircraft which may also impose a ballistic damage criterion, (2) windows for subsonic and supersonic crew compartments, (3) optical enclosures for helicopters, also with some resistance to small arms fire, etc. The several application analysis worksheets for optical transparencies will then provide a basis for subsequent material evaluation techniques analysis as described in Section II.

Any systematic data recording system will require that the component and environment classification of Tables 3 and 4 be suitably expanded and possibly extended to second or even third levels of detail. The system will also require

TABLE 5

**COMPONENT:** Pilot Canopy

**SYSTEM:** Fighter Aircraft (Supersonic)

| | MATERIAL CHARACTERISTICS | | | | | |
|---|---|---|---|---|---|---|
| **OPERATIONAL OR DESIGN ENVIRONMENT** | **SCREENING (Mat'l A, B, C . . . Z)** | | **SELECTION (Mat'l A, B, C, D)** | | **DESIGN DATA (Mat'l A)** | |
| | **TYPE** | **Avail. Test** | **TYPE** | **Avail. Test** | **TYPE** | **Avail. Test** |
| THERMAL:<br>Steady 275°F for 3 hrs/flt<br>Max 420°F for 5'<br>Min -65°F<br>Gradient: 275° ext to 100°int<br>Defogging 180°F<br>Natural Weathering: Sun, Humidity<br>Erosion: Wind, Rain, Sand<br>PRESSURE:<br>Internal<br>Steady 8 psi<br>Max 20 psi (burst)<br>External<br>Steady Gradient<br>Max 50 psi for 10 min underwater<br>OPTICS:<br>Transmission - Per Spec MIL-P-25690<br>Deviation - Critical Area - <1'<br>Other Area - <3'<br>SPECIAL REQUIREMENTS:<br>Ejection through Canopy | | | | | | |

an appropriate alpha-numeric coding system for easy entry into a computer-based data file. For example, a unique two-digit number can be arbitrarily assigned to each of the components listed in Table 3 and additional digits added to the right to denote second or third level breakdowns. Similar codes can be assigned to the environments of Table 4 and any second or third level descriptions. The Committee has not attempted to develop a fully definitive classification of components and environments and codes. This report merely suggests the line along which further studies should proceed. How this information will be used is developed further in the Sections which follow.

## B. Material Screening, Selection, and Design Data

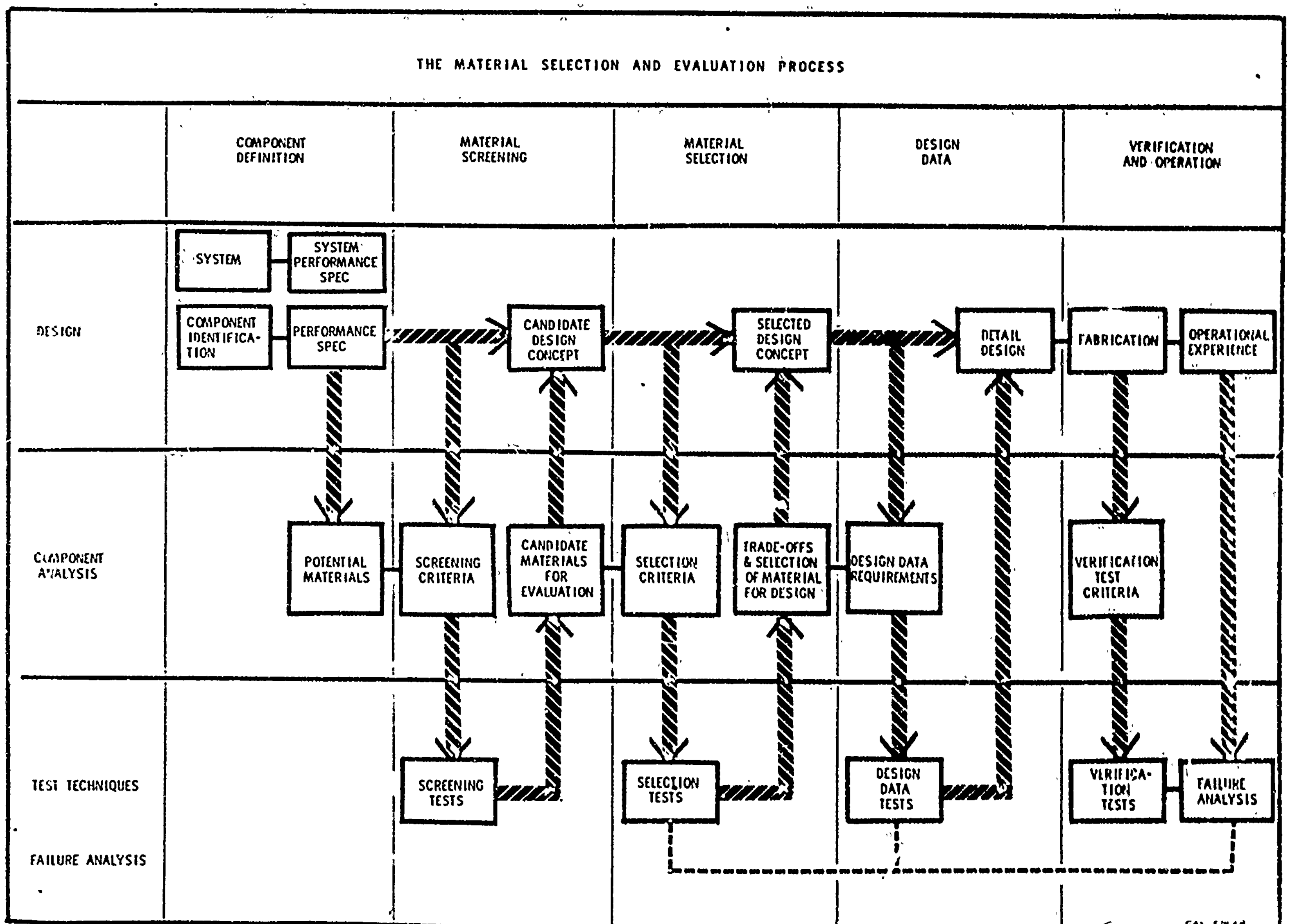
The material selection and evaluation process is reviewed briefly here as it applies specifically to load-bearing structures for aerospace applications. This is done to permit further definition of the terms employed and to provide a basis for subsequent analysis.

Figure 1 describes this process and relates the design, component analysis, and evaluation efforts to the several phases of the component development process ranging from the component performance requirements through the several component concept studies to the final design, fabrication, and test.

Three phases are commonly encountered during most material application studies. These are:

> The search for (among a large number of candidates) and subsequent narrowing down to a select few materials that look promising for the application. This will be called the Material Screening Phase.

FIGURE 1


THE MATERIAL SELECTION AND EVALUATION PROCESS
COMPONENT DEFINITION
MATERIAL SCREENING
MATERIAL SELECTION
DESIGN DATA
VERIFICATION AND OPERATION
DESIGN
COMPONENT ANALYSIS
TEST TECHNIQUES
FAILURE ANALYSIS
SYSTEM
SYSTEM PERFORMANCE SPEC
COMPONENT IDENTIFICATION
PERFORMANCE SPEC
CANDIDATE DESIGN CONCEPT
SELECTED DESIGN CONCEPT
DETAIL DESIGN
FABRICATION
OPERATIONAL EXPERIENCE
POTENTIAL MATERIALS
SCREENING CRITERIA
CANDIDATE MATERIALS FOR EVALUATION
SELECTION CRITERIA
TRADE-OFFS & SELECTION OF MATERIAL FOR DESIGN
DESIGN DATA REQUIREMENTS
VERIFICATION TEST CRITERIA
SCREENING TESTS
SELECTION TESTS
DESIGN DATA TESTS
VERIFICATION TESTS
FAILURE ANALYSIS

The trade-offs of material characteristics against each other and against component performance, cost, fabricability, and availability which results in the selection of the optimum material for the specific application. This will be called the Material Selection Phase.

The development in depth of certain material properties for the selected material to obtain statistically reliable measures of the material performance under the specific conditions expected to be encountered in service. This will be called the Design Data Phase.

The material properties to be evaluated during each of these three phases, therefore, will be called material screening properties, material selection properties, or material design data properties, depending upon their use. Thus, the short-time compression yield strength of a material for one application may serve as a screening property and as a selection property and, subsequently, as a design data property for the same component. For some other application the short-time compression yield strength may be of secondary interest during the screening phase but still be important during the selection phase.

For purposes of analysis, definitions of screening, selection, and design data, properties have been formulated that are consistent with the phase descriptions. These follow.

Screening Properties

Though the general concept of a screening property is readily accepted, the definition of exactly what constitutes a screening property is somewhat more elusive. If one states his definition in terms of "desirable" or "essential" material characteristics, he finds himself faced with a difficulty. For he will find

many properties which will be classed as "desirable," "critical," or even "essential," but this classification may not necessarily prove adequate to define a screening test program. This difficulty may be overcome partially by arbitrarily assigning an order of importance (or criticality) to the properties, but the fundamental difficulty of vagueness remains.

The word "screening" suggests the definition. For in the physical analogy of a mesh we are interested only in those samples of a population that either pass through the mesh or fail to pass through the mesh. The screen becomes a constraint, and the notion of a screening property as having a value "less than" or "greater than" some pre-assigned value is the key idea. From this follows the definition:

> A screening property is any material property for which an absolute lower (or upper) limit is established for the application in which it will be used, and no trade-off beyond this limit is tolerable.

The essential idea here is the setting of one-sided constraints or limits that permit a definite "yes" or "no" answer to the question: "Should this material be evaluated further for this application?"

Application of the screening property definition requires (1) for each material application an identification of those properties for which limits are required, and (2) specification of the limits.

Selection Properties

Definition: Selection properties are those properties required in the trade-off studies of the candidate materials.

By this definition material characteristics that pertain to its cost, fabricability and maintainability are also "selection properties." Alternate design approaches may result in different materials being selected. For

example, a monolithic magnesium may be the optimum material for a forging while a built-up design would use aluminum sheet.

Design Data Properties

Definition: Design data properties are those properties of the selected material in its fabricated state that must be known with sufficient confidence to permit the design and fabrication of a component which will function with a specified reliability.

"Reliability" as used in this definition is defined in the conventional sense as the probability that the component will function within specified limits for at least a specified period of time under specified environmental conditions.

The material selection and evaluation process for a particular application ranges from the extremes of a very few, but important, screening tests on a large number of materials to a large number of tests on the selected materials.

Since the cost of obtaining comprehensive design data properties for a single material can be very high, the identification of the significant screening properties for various typical applications can achieve cost savings by avoiding unnecessary or premature design data evaluation efforts. In addition, if the truly significant properties are identified early, reliable subsequent performance is made more likely.

## C. Material Performance Characteristics

The Committee formulated an initial listing of properties suitably classified as to mechanical, physical, thermal, etc., and these are presented as Table 6. Additional subcategories could be assigned if necessary. The intent of Table 6 is to suggest the nature of the material performance characteristics that must be identified as a basis for the subsequent development of a material evaluation data information system. The number of characteristics

## TABLE 6

### MATERIAL PERFORMANCE CHARACTERISTICS

#### MECHANICAL PROPERTIES

- Tension
  - Stress Strain Curve
    - To 0.2% offset
    - Complete curve
  - Tensile Properties
    - Ultimate
    - Yield
    - Elongation
    - Reduction of area
- Modulus of Elasticity
  - Static Tensile
  - Static Compression
  - Modulus of Rigidity
  - Dynamic Modulus
  - Poisson's Ratio
- Compression
  - Stress Strain Curve
    - To 0.2% offset
    - To 0.5% offset
  - Compressive Properties
    - Yield
- Bearing
  - Stress Deformation Curve
  - Bearing Properties
    - Yield
    - Ultimate
- Shear
  - Ultimate
  - Shear Yield in Torsion
- Fatigue Strength
  - Smooth
  - Notched ($K_t$=3.0)
  - Fretting
  - Rolling Contact
  - Corrosion Fatigue
- Creep
  - 0.1%
  - 0.2%
  - 0.5%
  - 1.0%
  - Rupture
- Crack Propagating Resistance
  - Notched Tensile Ratio ($K_t$ 3.0)
    - Definition
  - Notched Rupture Ratio ($K_t$ 3.0)
    - Definition
  - $K_{Ic}$
  - $K_c$
  - Slow Flaw Growth
- Impact Resistance
  - V Notch Charpy
- Wear Resistance
  - Galling
  - Abrasion Resistance
  - Erosion
- Stress Corrosion
- Ballistic Impact
- Damping
- Cavitation
- Spalling

#### PHYSICAL PROPERTIES

- Density
- Hardness
- Coefficient of Friction
- Vapor Pressure
- Viscosity
- Porosity
- Permeability
- Reflectivity
- Transparency
- Optical Characteristics
- Dimensional Stability

#### THERMAL PROPERTIES

- Conductivity
- Specific Heat
- Coefficient of Expansion
- Emissivity
- Absorptivity
- Melting Point
- Ablation Rate
- Flammability

#### ELECTRICAL PROPERTIES

- Dielectric Constant
- Hysteresis Loss
- Conductivity

#### NUCLEAR PROPERTIES

- Half Life
- Cross Section
- Stability

#### CHEMICAL AND METALLURGICAL PROPERTIES

- Corrosion
- Biological
- Thermal Stability
- Crazing
- Oxidation

#### FABRICABILITY PROPERTIES

- Weldability
- Machinability
- Heat Treatability
- Formability

#### FORMS

- Sheet
- Plate
- Bar
- Extrusion
- Forging
- Casting
- Tubing
- Powder and P/M parts

#### DETERIORATION

- Metallurgical

listed in Table 6 is illustrative of the dilemma facing the material evaluator and, of course, the problem expands manyfold when environmental conditions are superimposed as indicated in Table 7.

A logical process of material selection and evaluation must be based upon:

a. An appraisal of the loading conditions
b. Consideration of the effects of processing and fabrication
c. Consideration of the effects of service environment, including accidental conditions, which may modify structural or material behavior.

With this background, the engineer may then select a possible or anticipated mode of failure that might limit the useful life of the member.

The "analysis of failures" was one of the approaches taken to try to understand how one decides which properties to measure, in the selection of material or for design. An engineer designs a structural component to prevent failure; hence, he considers, "What are the <u>causes</u> leading to failure?" and "What are the <u>modes</u> of failure that might be anticipated?" For any particular mode of failure there are only a few significant material parameters that must be determined for selection of an optimum material. A careful review of the probable modes of failure that might be anticipated can serve as a valuable tool in answer to such questions as: (1) What material properties do I need to know? (2) What additional tests do I need to perform before making selection of the optimum material? (3) How significant are the mechanical properties data that I now have available on these materials? (4) Is the tensile strength a good parameter to measure the strength-to-weight ratio in this service condition? (5) What rational process can be used to select design stresses for this new and unique component? and (6) Is there a realistic method of estimating the probability of failure of this component during the intended service life? In applications where

TABLE 7

PORTIONS OF MATERIAL CHARACTERISTICS CODES FOR SCREENING, SELECTION, AND DESIGN

| SCREENING | | SELECTION | | DESIGN | |
|---|---|---|---|---|---|
| | Code | | Code | | Code |
| Tensile Strength/Density | 01 | Tensile at Critical Temp. | 01 | Tensile vs. Temperature | 01 |
| Notch Toughness | 02 | Compression at Crit. Temp. | 02 | Compression vs. Temperature | 02 |
| Notch Fatigue | 03 | Shear at Critical Temp. | 03 | Shear vs. Temperature | 03 |
| Thermal Stability | 04 | Bearing at Critical Temp. | 04 | Bearing vs. Temperature | 04 |
| Creep | 05 | Creep at Critical Temp. | 05 | Fatigue vs. Temperature | 05 |
| | . | | . | | . |
| | . | | . | | . |
| | . | | . | | . |
| | . | | . | | . |
| | 33 | | 59 | | 41 |

deterioration may be a major factor, additional simulated service testing may be necessary as insurance against occurrences of failures due to hydrogen embrittlement, corrosion fatigue failure, diffusion of foreign atoms at high-temperatures, etc. The Committee was not able to find a way to use failure analysis as a direct approach to development of a material evaluation system. However, it is acknowledged that failure analysis considerations, as mentioned above, must be inherent in the determination of the critical properties of materials.

The case history approach is the heart of the proposed materials evaluation system. Table 5 showed a means for recording the environmental conditions for a case history. Section B developed definitions for screening properties, selection properties, and design data properties. The matter of discipline in the preparation of case histories is one which needs strong emphasis. The definitions of screening, selection, and design data criteria must be consistently adhered to. Errors in the exact magnitude of the loading or in the environmental conditions may be tolerated to a considerable extent, but the properties which relate to the significant failure modes must not be overlooked. The usefulness of the entire system will depend upon how carefully the material performance characteristics for each case history are selected. Material evaluation must be just as concerned with finding out what is wrong with a material as it is with finding out what is good about a material. It is largely at this point that engineering judgment is introduced into the system.

## D. Recording of Significant Properties and Environments for Selected Applications

Various members of the Committee developed eight examples of aerospace load-bearing applications. These applications which are shown in Tables 8 through 15 include:

Supersonic Aircraft Pilot Canopy
Supersonic Aircraft Wing Panel
Supersonic Aircraft Leading Edge
Supersonic Aircraft Control Rods
Supersonic Jet Engine Turbine Blade - Air Cooled
Surface-to-Surface Missile Propellant Tanks - Unlined
Surface-to-Surface Missile Solid Propellant Motor Case
Surface-to-Air Missile Uncoated Rocket Motor Jet Vane

These applications were selected to demonstrate that the proposed classification system is broad enough to cover an extreme range of systems, vehicles, components, and environments, and that these considerations can all be related to the applicable material evaluation requirements. As indicated, this was done only for purposes of demonstration.

The screening properties listed in the second column of Tables 8 through 15 are only qualitatively described at this point. Application of these data is discussed in Chapter II which will consider means of assigning limit values, such as "not less than ___," or "not greater than ___," to the screening properties for specific applications.

When there are particular specifications relating to environmental criteria, such as fatigue spectra, or relating to material criteria, these should be noted on the case history.

TABLE 8

**COMPONENT:** Pilot Canopy **SYSTEM:** Fighter Aircraft (Supersonic)

| | MATERIAL CHARACTERISTICS | | | | | |
|---|---|---|---|---|---|---|
| OPERATIONAL OR DESIGN ENVIRONMENT | SCREENING (Mat'l A, B, C . . . Z) | | SELECTION (Mat'l A, B, C, D) | | DESIGN DATA (Mat'l A) | |
| | TYPE | Avail. Test | TYPE | Avail. Test | TYPE | Avail. Test |
| THERMAL:<br>Steady 275°F for 3 hrs/flt<br>Max 420°F for 5 min/flt<br>Min -65°F<br>Gradient: 275° ext to 100°int<br>Defogging 180°F<br>Natural Weathering: Sun<br>Humidity<br>Erosion: Wind, Rain, Sand | Luminous Transmittance<br>Color Stability<br>Tensile Strength | | Tensile Strength/Density<br>Compression Strength/<br>Density<br>Craze Resistance<br>Limits<br>Modulus of Elasticity<br>Crack Propagation<br>Characteristics | | Tensile Strength<br>vs. Temp<br>Compression<br>Strength<br>Edge Joints -<br>Tension | |
| PRESSURE:<br>Internal<br>Steady 8 psi<br>Max 20 psi (burst)<br>External<br>Steady Gradient<br>Max 50 psi for 10 min<br>underwater | Craze Resistance<br>Crack Propagation<br>Resistance<br>Max*<br>Min | | Thermal Expansion<br>Specific Heat<br>Thermal Conductivity<br>Creep<br>Dimensional Stability | | Creep<br>Stress Rupture<br>Fabrication<br>Limits<br>Joining<br>Stretching | |
| OPTICS:<br>Transmission - Per Spec<br>MIL-P-25690<br>Deviation - Critical Area -<br><1'<br>Other Area -<br><3' | Notch Fatigue<br>*Measure of ability to<br>Eject through Canopy | | Fabricability Tests<br>Joinability (Bonding)<br>Formability | | | |
| SPECIAL REQUIREMENTS:<br>Ejection through Canopy | | | Trade-Off Factors:<br>Availability<br>Fabricability<br>Weight, Cost<br>Shape of Canopy | | | |

TABLE 9

**COMPONENT:** Wing Panel (Skin) **SYSTEM:** Aircraft (Supersonic)

| OPERATIONAL OR DESIGN ENVIRONMENT | MATERIAL CHARACTERISTICS | | | | | |
|---|---|---|---|---|---|---|
| | SCREENING (Mat'l A, B, C . . . Z) | | SELECTION (Mat'l A, B, C, D) | | DESIGN DATA (Mat'l A) | |
| | TYPE | Avail. Test | TYPE | Avail. Test | TYPE | Avail. Test |
| LOAD: 25,000 lb/in<br>LIFE: 30,000 hrs<br>THERMAL: 550°F<br>CHEMICAL: Hydrocarbon Fuel & Atmosphere | Tensile Strength/Density<br>Notch Toughness<br>Notch Fatigue<br>Thermal Stability<br>Creep<br>Stress Corrosion<br>Modulus/Density<br>% Elongation | | Tensile at Critical Temps<br>Compression "<br>Shear at Critical Temps<br>Bearing at Critical Temps<br>Fatigue at Critical Temps<br>Creep at Critical Temps<br>Toughness "<br><br>Fabricability Tests:<br>Machinability<br>Formability<br>Weldability<br>Heat Treatment<br><br>Trade-Off Factors:<br>Availability & Timing<br>Fabricability<br>Forms & Tolerances<br>Design Concepts<br>Weight<br>Cost<br>Reproducibility<br>NDT Requirements | | Tensile vs. Temp<br>Compression vs. Temp<br>Shear vs. Temp<br>Bearing vs. Temp<br>Fatigue vs. Temp<br>Creep vs. Temp<br><br>Conductivity<br>Coeff. of Thermal Expansion<br>Specific Heat<br>Thermal Stability<br>Toughness<br><br>Fabrication Limits<br>Weldability<br>Formability<br>Heat Treatment<br>Fastening and Joining<br><br>Tests After Load & Thermal Exposure | |

TABLE 10

**COMPONENT:** Leading Edge **SYSTEM:** Aircraft (Supersonic)

| | MATERIAL CHARACTERISTICS | | | | | |
|---|---|---|---|---|---|---|
| OPERATIONAL OR DESIGN ENVIRONMENT | SCREENING (Mat'l A, B, C . . . Z) | | SELECTION (Mat'l A, B, C, D) | | DESIGN DATA (Mat'l A) | |
| | TYPE | Avail. Test | TYPE | Avail. Test | TYPE | Avail. Test |
| THERMAL: 1200°F | Tensile Strength/Density | | Tensile at Critical Temps | | Tensile vs. Temp. | |
| DYNAMIC PRESSURE: 8 psi | Fracture Toughness | | Compression " | | Compression | |
| Db LEVEL: 165-185 | Oxidation Resistance | | Shear at Critical Temps | | Shear | |
| LIFE: 30,000 hrs | Corrosion Resistance | | Bearing at Critical Temps | | Bearing | |
| | Creep Deformation | | Fatigue at Critical Temps | | Creep | |
| | | | Creep at Critical Temps | | | |
| | | | Toughness " | | Thermal Conductivity | |
| | | | Erosion | | Specific Heat | |
| | | | Impact Resistance | | Thermal Stability | |
| | | | Coeff. of Thermal Expansion | | Fabrication Limits | |
| | | | Fabricability Tests: | | Formability | |
| | | | Machinability | | Fastening and Joining | |
| | | | Formability | | Weldability | |
| | | | Weldability | | Heat Treatment | |
| | | | Heat Treatment | | | |
| | | | Trade-Off Factors: | | | |
| | | | Availability & Timing | | | |
| | | | Fabricability | | | |
| | | | Forms & Tolerances | | | |
| | | | Design Concepts | | | |
| | | | Weight | | | |
| | | | Cost | | | |
| | | | Reproducibility | | | |
| | | | NDT Requirements | | | |

TABLE 11

**COMPONENT:** Control Rods **SYSTEM:** Aircraft (Supersonic)

| OPERATIONAL OR DESIGN ENVIRONMENT | MATERIAL CHARACTERISTICS | | | | | |
|---|---|---|---|---|---|---|
| | SCREENING (Mat'l A, B, C . . . Z) | | SELECTION (Mat'l A, B, C, D) | | DESIGN DATA (Mat'l A) | |
| | TYPE | Avail. Test | TYPE | Avail. Test | TYPE | Avail. Test |
| THERMAL: -65° to 250°F<br><br>LOAD: < 2000 lbs<br><br>LIFE: 30,000 hrs<br><br>VIBRATION: Natural Frequency Not close to Measured Exciting Frequencies | Stiffness/Density<br><br>Compression Yield Strength | | Stiffness/Density<br>Tensile Strength/Density<br>Fatigue<br>Stress Corrosion<br><br>Fabricability Tests<br>Formability<br>Machinability (holes)<br>Weldability<br><br>Trade-Off Factors<br>Availability & Timing<br>Fabricability<br>Weight<br>Cost<br>Vulnerability | | Tensile Strength<br>Bearing Strenth<br>Fatigue<br>Compression Yield<br><br>Fabrication Limits<br>Weldability<br>Formability | |

TABLE 12

**COMPONENT:** Air Cooled Turbine Blade **SYSTEM:** Jet Engine (Supersonic Cruise)

| | MATERIAL CHARACTERISTICS | | | | | |
|---|---|---|---|---|---|---|
| OPERATIONAL OR DESIGN ENVIRONMENT | SCREENING (Mat'l A, B, C . . . Z) | | SELECTION (Mat'l A, B, C, D) | | DESIGN DATA (Mat'l A) | |
| | TYPE | Avail. Test | TYPE | Avail. Test | TYPE | Avail. Test |
| 1) STATIC<br>Temp. 1900°F<br>Life 15,000 hrs<br>(Sulfidation) Combustion Products<br>2) ALTERNATING<br>1600°F<br>15,000 hrs<br>3) THERMAL SHOCK<br>1600°F<br>15,000 cycles | Stress Rupture/Density at Given Conditions<br>Reduction at Area<br>Fracture Toughness<br>Corrosion Resistance at Given Conditions | | Tensile at Critical Temps<br>Modulus at Critical T<br>Thermal Expansion at $T_c$<br>Fatigue Smooth at $T_c$<br>Fatigue Notch at $T_c$<br>Erosion Resistance at $T_c$<br>Corrosion Resistance at $T_c$<br>Thermal Stability at $T_c$<br>Creep at $T_c$<br>Stress Rupture at $T_c$<br>Fabricability Tests:<br>Formability<br>Castability<br>Machinability<br>Trade-Off Factors:<br>Availability & Timing<br>Fabricability<br>Forms & Tolerances<br>Design Concepts<br>Weight<br>Cost<br>Reproducibility<br>NDT Requirements | | Tensile vs. Temp<br>Dyn. Modulus vs T<br>Thermal Exp. vs T<br>Thermal Cond vs T<br>Emissivity<br>Spec. Heat<br>Fatigue Smooth<br>Notched<br>Low cycle<br>Erosion Resistance<br>Corrosion Resistance<br>Thermal Stability<br>Creep (.2%)<br>Rupture | |

TABLE 13

**COMPONENT:** Propellant Tanks (Unlined) **SYSTEM:** Missile - Tactical - Surface to Surface

| | MATERIAL CHARACTERISTICS | | | | | |
|---|---|---|---|---|---|---|
| OPERATIONAL OR DESIGN ENVIRONMENT | SCREENING (Mat'l A, B, C . . . Z) | | SELECTION (Mat'l A, B, C, D) | | DESIGN DATA (Mat'l A) | |
| | TYPE | Avail. Test | TYPE | Avail. Test | TYPE | Avail. Test |
| LOAD/LIFE: | Short Time Tensile Strength/Density | | Strength/Density at Operating Temperature | | Tension Strength | |
| Internal Pressure: 2100 psi (22 in dia) | Modulus of Elasticity/Density | | Fracture Toughness | | Shear Strength | |
| Storage Life: 10 years | Transition Temp | | Specific Heat | | Bearing Strength | |
| THERMAL: | Stress Corrosion | | Thermal Conductivity | | Compression Yield | |
| Storage: -65°F to 155°F | Corrosion Rate | | Fabricability Tests: Formability, Machinability, Weldability, Heat Treatability | | Poisson's Ratio | |
| Operation: Aerodynamic plus internal heating | Shock Sensitivity | | Trade-Off Factors: Cost, Available Forms, (Casting, Forging, etc.), Design Concept, Tolerance Limits | | Thermal Expansion | |
| CHEMICAL: | Specific Heat | | | | Fabrication Limits: Welding, Heat Treating | |
| External Atmosphere (world-wide) | | | | | | |
| Internal Propellants: e.g.: IRFNA, UDMH | | | | | | |

TABLE 14

COMPONENT: Rocket Motor Case Solid Propellant

SYSTEM: Missile: Tactical-Surface to Surface

| | MATERIAL CHARACTERISTICS | | | | | |
|---|---|---|---|---|---|---|
| OPERATIONAL OR DESIGN ENVIRONMENT | SCREENING (Mat'l A, B, C . . . Z) | | SELECTION (Mat'l A, B, C, D) | | DESIGN DATA (Mat'l A) | |
| | TYPE | Avail. Test | TYPE | Avail. Test | TYPE | Avail. Test |
| LOAD/LIFE:<br>Internal Pressure: 650 psi (40 in diameter)<br>Storage Life: 10 years<br>THERMAL:<br>Storage: -25°F - 125°F<br>Operation: Aerodynamic Heating<br>Heat Flux - 2 BTU/SF/Sec<br>CHEMICAL:<br>Atmosphere (world-wide) | Short Time Tensile Strength/Density<br>Modulus of Elasticity/ Density<br>Transition Temp<br>Stress Corrosion | | Strength/Density vs. Temp<br>Fracture Toughness<br>Thermal Conductivity<br>Specific Heat<br>Fabricability Tests:<br>Formability<br>Machinability<br>Weldability<br>Heat Treatability<br>Trade-Off Factors:<br>Cost<br>Available Forms; (Casting, Forging, etc.)<br>Design Concept<br>Tolerance Limits | | Tension Strength<br>Shear Strength<br>Bearing Strength<br>Compression Yield<br>Poisson's Ratio<br>Thermal Expansion<br>Fabrication Limits<br>Welding<br>Heat Treating | |

TABLE 15

**COMPONENT:** Rocket Motor Jet Vane (Uncoated) **SYSTEM:** Missile (Low Altitude - Surface to Air)

| OPERATIONAL OR DESIGN ENVIRONMENT | MATERIAL CHARACTERISTICS: SCREENING (Mat'l A, B, C . . . Z) | | SELECTION (Mat'l A, B, C, D) | | DESIGN DATA (Mat'l A) | |
|---|---|---|---|---|---|---|
| | TYPE | Avail. Test | TYPE | Avail. Test | TYPE | Avail. Test |
| LOAD/LIFE:<br>Exposure to Solid Propellant Exhaust Gases for 2 Seconds<br>Exit temperature 2700°F<br>Exit pressure 96 psi<br>Exit velocity 2.5 MN | Shear Strength/Density at Temp.<br>Modulus of Elasticity at Temp. | | Shear Strength<br>Tensile Strength<br>Modulus of Elasticity<br>Fracture Toughness<br>Erosion<br>Spalling<br>Cavitation<br>Thermal Shock | | Tension Strength<br>Shear Strength<br>Bearing Strength<br>Erosion<br>Spalling<br>Cavitation<br>Thermal Shock | |
| THERMAL:<br>Flame temperature 2900 - 3000°F<br>Specific Heat Ratio 1.22<br>Minimum Operating Temp - 40°F<br>Storage: -65°F - 165°F | Specific Heat<br>Thermal Conductivity<br>Melting Point | | Specific Heat<br>Thermal Conductivity<br>Thermal Expansion<br>Fabricability Tests:<br>Formability<br>Machinability<br>Weldability<br>Trade-Off Factors:<br>Cost<br>Available Forms<br>Tolerance Limits<br>Design Concept | | Fabrication Limits<br>Welding | |

As must be evident by now, the Committee feels that the most important material evaluation decisions are those relating to the properties which are to be determined. Having established this premise, it is also acknowledged that the exact technique by which these properties are determined is also important. While the techniques are important, they are not of primary importance provided conditions of test and response of the material are adequately defined. If it were possible, it would be very convenient to obtain agreement that for every property of concern there was only one "approved" technique for determining that property. The Committee does not wish to be drawn into this controversy where there is already so much activity on the part of other committees.

Having proposed a useful scheme by which it is possible to ascertain the properties which should be determined for a broad spectrum of applications, it is realized that it would be useful to relate this to actual test techniques. In considering what useful information might be presented, the Committee has followed a previously-used process that was helpful. The Committee has asked itself what questions one might have when he uses the proposed approach. These questions are as follows:

1. For a particular category of test,
   a. What test specifications exist, if any?
   b. Which test specifications are most commonly used?
   c. Does the test provide data of direct use in structural analysis?
   d. What is the reason for unreliable results and/or results which are biased by the choice of equipment or operator?
2. For a particular category of test which may be very specialized,
   a. Where do these specialized capabilities exist?
   b. What references describe these tests?
   c. What are the limitations of the test conditions?

3. For what applications are certain tests used?
4. In what test areas is standardization lacking?
5. In developing a material for a given application, what specific tests should be performed?
6. Can correlation with service be demonstrated?

The Committee believes and has demonstrated that pertinent information relative to the above questions can be entered on worksheets such as Table 8. When a sufficient number of these worksheets have been prepared, a coding system can be established as it has been for properties so that all of this information can be conveniently stored in a computer for systematic retrieval.

If the overall system being proposed herein is to be useful in influencing material evaluation decisions, it will be necessary to create a large number of additional case histories which can be coded for storage in a computer. The Committee has not devised a system for selecting the case histories which should be developed, but it seems obvious that the type of case histories to be developed must depend upon the queries which will be made of the system, i.e., the scope of interest of the users.

These queries may be component-oriented, in which case, the case histories for selected families of components would be required, or they may be environment-oriented, e.g., aerospace-hypersonic, in which case, the requirements for components operating in a hypersonic-aerospace environment would be evaluated or still other broad categories could be considered. Table 16 indicates some of the possible application classifications in the column at the left. The eight components used in this report are identified relative to these classifications.

Some of these questions will be more specifically formulated in the next section of the report.

TABLE 16

SAMPLE AEROSPACE LOAD BEARING STRUCTURE APPLICATIONS

| Application Classification | Skin Panel | Leading Edge | Pilot Transparency | Control Rods (Actuators) | Turbine Blade | Pressure Vessel 2 Examples | Rocket Nozzle Vane |
|---|---|---|---|---|---|---|---|
| 1. Aerospace Environment | | | | | | | |
| a. Subsonic | | | | | | | |
| b. Supersonic | x | x | x | x | x | xx | x |
| c. Hypersonic | | | | | | | |
| d. Space Reentry | | | | | | | |
| e. Space | | | | | | | |
| 2. Vehicle/Equipment System | | | | | | | |
| a. Aircraft | x | x | x | x | x | | |
| b. Missile | | | | | | xx | x |
| c. Launch Vehicle | | | | | | | |
| d. Space Vehicle | | | | | | | |
| e. Ground Support | | | | | | | |
| 3. Vehicle/Equipment Subsystem | | | | | | | |
| a. Airframe | x | x | x | | | | |
| b. Powerplant | | | | | x | x | x |
| c. Secondary Power System | | | | x | | | |
| d. Fuel System | | | | | | x | |

## II. PROPOSED TECHNIQUES FOR SYSTEMATIC EVALUATION OF MATERIALS

A truly useful and comprehensive material evaluation data information system is urgently needed.

The questions that are being asked every day by someone in the Government, in the materials industry, or by major systems manufacturers, amply testify to this. Each question implies an uncertainty concerning a decision to commit valuable resources for research evaluation, development, or production, and their associated facilities. The process of finding the answers to the questions is frequently expensive and time-consuming. The answers are rarely hard firm "yes" or "no" answers, but involve value judgments concerning the uncertainties which condition the available information for the several alternatives.

Some of the pertinent questions being asked are listed in Table 17.

Is it reasonable to expect that some or all of these questions can be answered by a computer? The Committee thinks so.

Current and projected developments in computer technology, notably in data storage and access, suggest that a modern material application and evaluation data system can be much more than an information retrieval system. The possibilities for computer analysis of the stored data to provide answers to the kinds of questions listed in Table 17 appear to be unlimited.

For example, suppose that one of the Services is considering the question of how much R & D funding to spend on evaluating a new material. The new material has outstanding yield strength/density in the 1000-1500°F temperature range, as shown in Figure 2. On the debit side the material has poor creep-resistance, costs $50/pound and is available only as a forging. Several potential

## TABLE 17

## MATERIAL EVALUATION AND APPLICATION QUESTIONS

I. Typical questions asked by the Military Services

A. Should R&D funds be spent to evaluate this material?

1. If so, what kinds of evaluation tests?
2. To what depth?
3. Are tests available?
4. Are they realistic?

B. Given a new application --

1. What materials are potentially available?
2. What tests are needed to find out?
3. What are the missing material performance characteristics?
4. Are materials available in the required forms, or can they be made?

II. Typical Questions asked by materials producers

A. How much should I spend to improve a specific material property? (Is this material sufficiently advanced over present materials to be worth the effort?)

B. What types of tests correspond to probable market application?

C. What are critical tests to see if the material is acceptable at all? (Recall the stress corrosion cracking problem.)

D. Will there be a market by the time production will take place?

E. What quality levels are needed?

F. What acceptance tests will purchasers impose? How expensive will they be?

G. Where is it likely to be used?

H. What are the most critical tests to establish if more detailed testing is justified?

TABLE 17 (continued)

I. What data should one have on hand before approaching a potential user?

J. How much improvement must be made in undesirable attributes before the new material will be considered?

K. What new test methods are needed for the new environment?

III. Typical questions asked by system manufacturer

A. What are potential applications and payoffs?

B. When will material be available?

C. What about material reproducibility, tolerances, quality assurance?

D. What unique fabrication aspects are involved?

E. What is an efficient method to evaluate materials for a specific application?

F. What are all the general considerations necessary in applications of materials to a specific component?

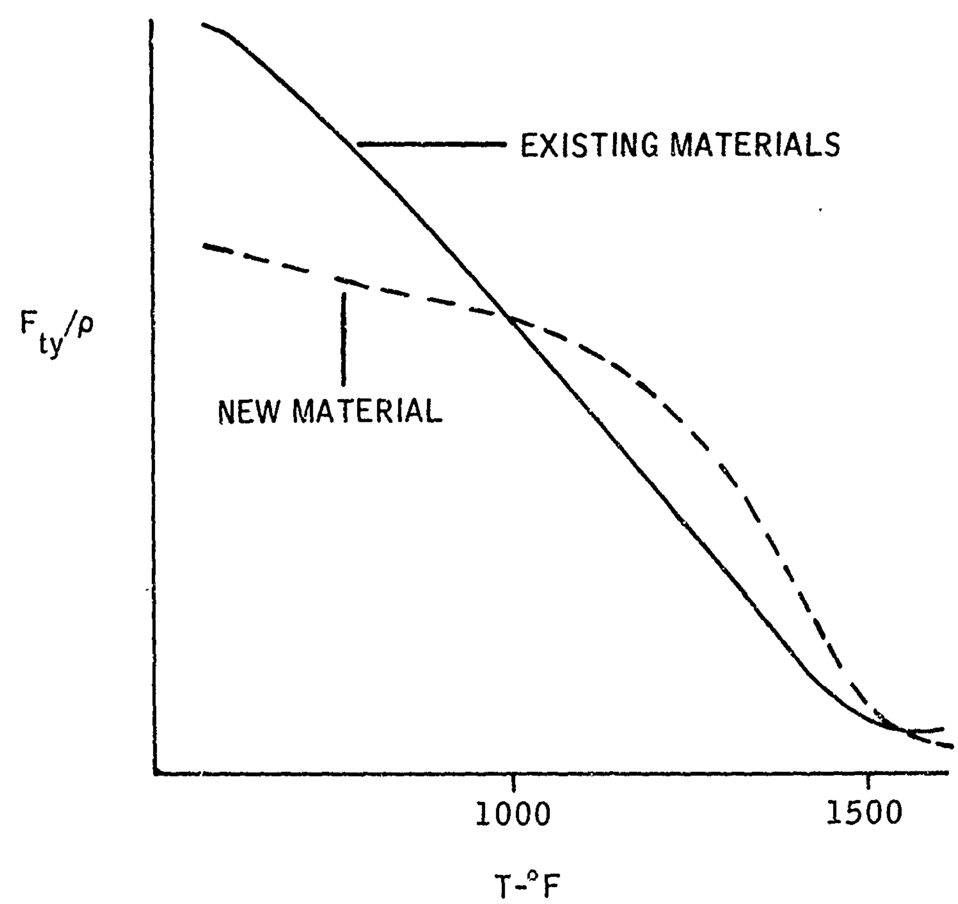
G. What are the "best" standard methods to evaluate the many and complex properties?

H. When needed, what are guidelines for developing specialized materials tests?

I. What are guidelines for trade-offs in materials selections (for example, cost, usage, availability)?

J. What are the areas in which material improvement is needed?

FIGURE 2



users have indicated an interest in the material. The improvement in properties appears to be highly dependent upon the close control of a unique material processing technique. To produce the material in large quantity would require a large capital investment on the part of the producer and some assurance of a market is needed before making such a commitment.

Since a detailed evaluation of the material can be very expensive, it is important that the critical material evaluation tests be known. To do this, one must first define the most likely applications for this new material. Then, the several critical characteristics that the material must possess must be known if the higher yield-strength is to be exploited. Finally, one must know whether the materials evaluation techniques available are suitable for this particular material and its environment. With this information in hand, some idea is possible of the likely extent of the usage of the new material as well as some guidance as to the scope of the required evaluation program. To answer these questions with the aid of a computerized information retrieval system, the materials engineer or designer would use an input/output terminal connecting his office by wire to a central processing unit that might be located several hundred miles away. The engineer would first type out a system code and an identification code. The first code would alert the computer that it is being addressed in connection with the materials evaluation information system and load the program into core. The second code would contain information as to the questioner's name, organizational unit, and authorization to have access to the information. The computer would type or display instructions to the engineer as to how to interrogate the machine. The engineer might then type in the following question:

"What applications require high $F_{ty}/\rho$ in the 1000-1500°F range?"

The machine would respond by typing out all applications identified by type of system and component for which $F_{ty}/\rho$ is a specific requirement in this temperature range. This question related only to $F_{ty}/\rho$ and ignored the deficiency in creep-strength. A second question could be asked:

"Which of these applications involve lifetimes of less than .1 hr, 1 hr, 10 hr, 100 hr, or 1000 hr?"

The answer from the computer has now considerably narrowed the field. The next question might be:

"Which of the remaining applications require forgings?"

Now the answers are becoming very definitive. We might now ask three other questions:

"What are the screening, selection, and design data properties that are needed for the applications where this material is advantageous?"

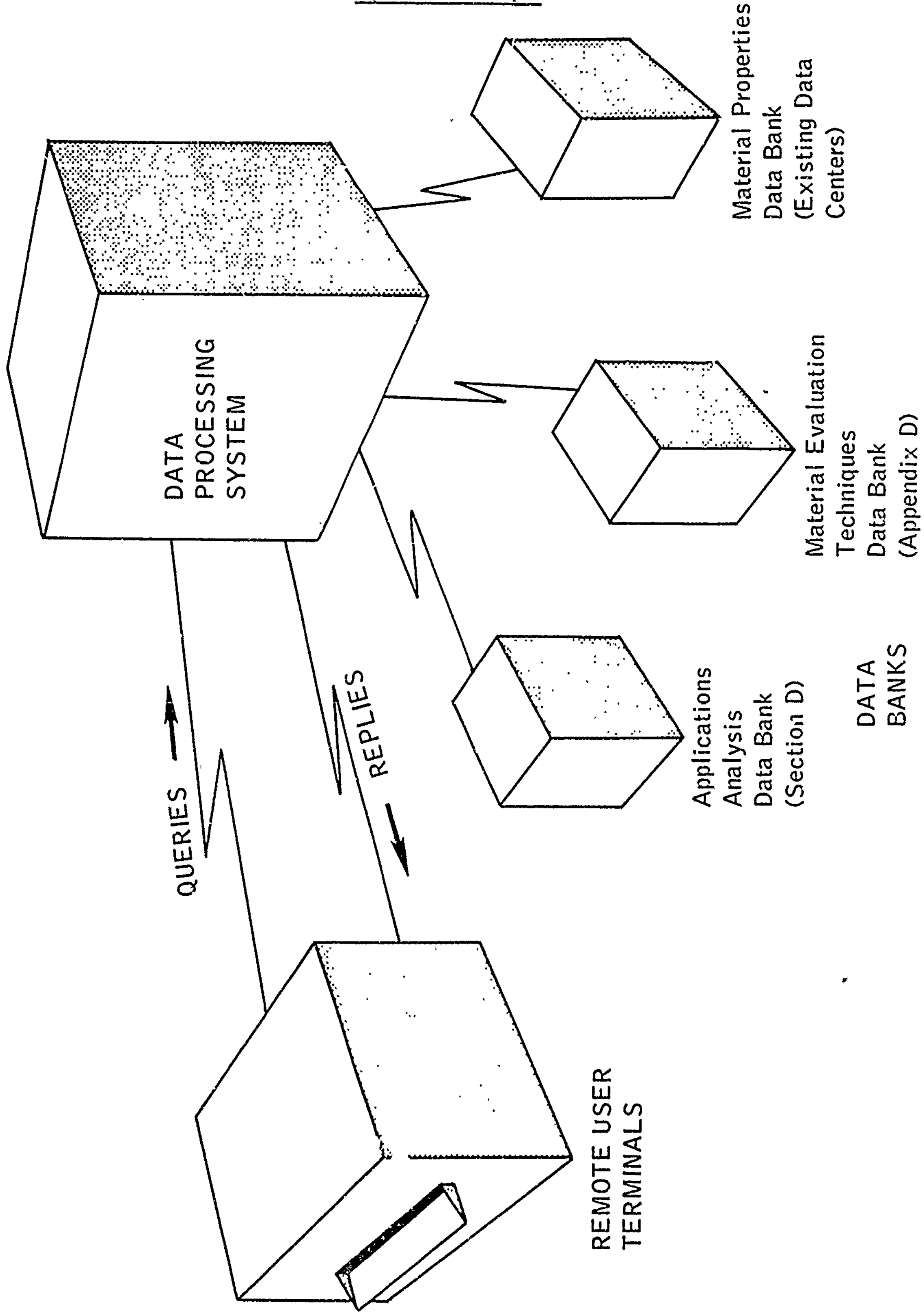
"What are the competing materials and what are their properties?"

"If this material could be made available as a sheet product, where might it be used?"

As can be seen, it will be important to ask questions carefully in order to obtain the desired answers. It should also be apparent that the computer can do an essential job of data retrieval which would be very laborious if only case history and data files existed.

The general concept for such a system is shown in Figure 3. It consists of the input/output terminals which are located in the using offices, the central data processor which may be located almost anywhere and to which the input/output terminals are linked by telephone wires, and the data banks which also may be located separately from either the terminals or the processor. As an intermediate step, instead of having a direct communication between the user and the machine by means of the input/output terminals, the user would present his queries to a data analyst at the central computer facility. This person would be a knowledgeable materials application engineer who would serve as the buffer between the user and the machine. The data analyst would work with those in charge of the data banks to control the changes and/or additions to the banks.

FIGURE 3. System Concept



In either case, development and maintenance of comprehensive data banks are essential to the success of the system.

A material evaluation requirements information system will require a minimum of two types of data banks:

1. An applications analysis data bank containing requirements for screening, selection, and design data material characteristics.
2. A material evaluation techniques data bank containing information relative to the availability, applicability, and limitations of material test and evaluation techniques.

It is the combination of raw data on materials properties with other considerations (requirements, availability, and limitations of evaluation procedures) which sets the proposed system apart from existing data centers. The availability of two data banks mentioned above would permit the answers to the types of questions listed by Table 18 and in Section ID.

If the currently available data banks on specific material characteristics and properties are integrated with the first two types of data banks, a base for the development of a comprehensive material evaluation data information system will exist, and the queries shown in Table 19 can be asked in addition to those shown in Table 18.

It is clear from the nature of the queries shown in Tables 18 and 19 that a material evaluation data information system should have a number of important and very useful applications. Chief among these will be:

Specification of required screening or selection tests for any specific application.

Quick access to available test data applicable to a specific application.

TABLE 18

TYPICAL QUERIES THAT CAN BE DIRECTED
TO A MATERIAL EVALUATION REQUIREMENTS INFORMATION SYSTEM

A. GIVEN: A NEW APPLICATION

QUERIES:

1. What is the operational environment of the material application?
2. What are the significant material requirements?
3. What material forms are required?
4. What material screening tests are required?
5. What material selection tests and trade-offs are required?
6. What kinds of design data are required?
7. Are adequate test techniques available to evaluate the key performance characteristics of candidate materials in the specified forms?

B. GIVEN: A NEW OR IMPROVED MATERIAL EVALUATION TECHNIQUE

QUERIES:

1. What applications will benefit from this improved technique?
2. What is the value of the improved test technique? (Benefit-Cost?)

C. GIVEN: EXISTING STATE-OF-ART

QUERIES:

1. What current applications require a specified material property or characteristic? With what frequency?
2. For what applications will an improvement in a specific material characteristic be beneficial?
3. What are current testing inadequacies by frequency of occurrence?

TABLE 19

ADDITIONAL QUERIES THAT CAN BE ASKED OF
A TOTAL MATERIALS EVALUATION DATA INFORMATION SYSTEM

A. GIVEN: A NEW APPLICATION

QUERIES:

8. What materials are available that may meet the requirements specified in response to question A-2 (of Table 18).

9. What are the missing material performance characteristics for a specific material of interest?

B. GIVEN: A NEW OR IMPROVED MATERIAL EVALUATION TECHNIQUE

QUERIES:

3. For what materials will this improved test technique be useful?

C. GIVEN: EXISTING STATE-OF-THE-ART

QUERIES:

4. What available materials possess a specified characteristic?

D. GIVEN: A NEW OR IMPROVED MATERIAL (IN A SPECIFIED FORM)

QUERIES:

1. What are the potential applications for this new or improved material?

2. What material evaluation tests are required for these applications?

3. What types of material screening tests are required?

4. What are the selection factors?

5. What types of design data are needed for a selected potential application?

6. What are the test environments?

7. Are adequate test techniques available?

8. What is the value of a specific improved material characteristic?

Rapid screening of available materials to a select few for specific applications.

Rapid survey of potential applications for a material possessing specified characteristics.

Determination of the value of an improved material characteristic.

Determination of the worth of an improved (or new) test technique.

To demonstrate the feasibility of programming an information system that would permit useful queries to be addressed to the computer, the data generated for the eight components of Tables 8-15 were coded for machine retrieval.* A full description of this program could logically be the subject of a separate report. In this report, it is not considered necessary or even desirable to fully describe the program. Suffice it to say that the Committee and its guests were given a demonstration of the feasibility of coding the input data in such a way that they could be manipulated to give back answers to the many questions which are relevant to the materials evaluation problem. Without the use of a computer program, the task would be unmanageable. It was concluded that:

a. A machine data system is feasible.

b. Useful queries and answers can be generated.

c. Maximum utility will require comprehensive data bank development and continual upgrading.

Recommended follow-on effort includes:

a. Preparation of additional worksheets including the suggested comments on test techniques.

b. Refinement of coding techniques.

---

*The extensive assistance of Mr. Donald Ryan and others of LTV is acknowledged with thanks.

c. Development of a technique for tying in the suggested materials evaluation system to the existing materials information centers.

d. Development of an efficient computer program.

e. Maintaining the system by keeping the data banks filled with up-to-date applications, test techniques, and materials property data.

## CONCLUSIONS

1. The Committee concurred that the present manner of dealing with the materials evaluation problem is increasingly inefficient. An improved procedure could enhance the likelihood that optimum materials are, in fact, selected, and could probably also save money by reducing needless testing and by decreasing the likelihood of promoting new materials which will later be found to be unsuitable.

2. Attempts to determine meaningful material evaluation trends or patterns from the several case histories developed in depth early in the life of the Committee were unproductive.

3. A potentially promising approach to criteria for a material evaluation technique appeared to lie in the use of failure analyses. The Committee was unable to develop this approach successfully because of the general lack of documentation concerning actual service failures and the factors existing at failure. This approach, nevertheless, may warrant further study.

4. Examination of the suitability and availability of material evaluation test techniques confirmed the generally well-known problems concerned with the attempts to develop useful tests that correlate well with service experience. A survey and an evaluation of all available test techniques were beyond the scope of the Committee charter.

5. The Committee concluded that the development of guidelines for material evaluation requires the analysis of numerous case histories for specific material applications.

6. The need for the analysis and recording of data for numerous case histories caused the Committee to address itself to the feasibility of developing a computerized approach to the data handling.

7. The Committee concluded that not only does a computerized approach appear feasible, but that, if developed, it could be useful to the Government, the using industry, and the materials producers.

8. The full development and utilization of a computerized approach to material evaluation will require the on-going development of a data bank relating material applications requirements and environments to specific components and systems. A second data bank containing information on the availability and adequacy of specific material test techniques will also be valuable.

9. The present status of Government programs in support of materials information data banks and other national technology information retrieval systems (such as, the Mechanical Properties of Materials Center, the Thermo-Physical Properties Research Center, and the Plastics Technical Evaluation Center) should be reviewed to determine where useful areas of cooperative effort may exist in the development of software and data management.

## APPENDIX A

## SYNOPSIS OF ACTIVITIES

This Committee has considered the general problem of materials evaluation. The areas of materials application include Air Force, Army, and Navy systems. Our considerations were focused upon materials which serve a structural function. By agreement, composites and classically brittle materials were excluded to avoid further complicating a difficult subject. A primary aim of the Committee was to develop an applications-oriented materials evaluation system. Because this system is not complete, it seems advisable to review the deliberations of the Committee so that others who may work on this subject in the future will realize how the recommendations being made were developed.

Table I is a tabulation of the dates and locations of the meetings which were held.

An earlier ad hoc Committee met in March 1966 in response to an Air Force request for the formulation of an MAB Committee to study the problem of materials evaluation techniques (see Appendix A). At this meeting it was agreed that the type of materials evaluation system that is needed is one that is based upon intended applications. Some of the members of the ad hoc Committee had served on the MAB Aerospace Applications Requirements Panel (AARP) which had recently published an extensive four volume report covering aerospace manufacturing requirements for the 1970-1985 period.* This study was applications-oriented and contained information about intended systems components and environments. It seemed logical that a materials evaluation approach could be developed on the foundation of the AARP reports. The ad hoc Committee discussed and developed

*MAB-200-M (AAP1 thru 4), "Requirements for Systems-Operational and Environmental, Aerospace Design, and Aerospace Manufacturing."

## TABLE I

### MEETINGS CONCERNED WITH MATERIAL EVALUATION TECHNIQUES

| Date | Group | Location |
|---|---|---|
| March 15, 1966 | *ad hoc* Committee | MAB-Washington, D. C. |
| March 1, 1967 | Full Committee | MAB-Washington, D. C. |
| May 11,12, 1967 | Full Committee | McDonnell, St. Louis |
| August 2, 3, 1967 | Full Committee | AMRA, Watertown, Mass. |
| October 30, 31, 1967 | Full Committee | General Electric, Evendale Ohio |
| February 5, 1968 | Matrix Group | MAB-Washington, D. C. |
| February 6, 7, 1968 | Full Committee | MAB-Washington, D. C. |
| April 17, 18, 1968 | Matrix Group | O'Hare International Inn, Chicago, Ill. |
| May 22, 23, 1968 | Full Committee | O'Hare International Inn, Chicago, Ill. |
| August 2, 1968 | Starr-Ryan-King | LTV-Dallas, Texas |
| September 11, 12, 1968 | Full Committee | MAB-Washington, D. C. |

an intended program of ten steps which, it believed, would lead to an excellent materials evaluation techniques system. These ten steps were:

1. Identify the types of vehicles or devices to be considered in the study.

2. Identify the vehicle (or device) components to be considered.

3. Identify component design environment.

4. Identify (or summarize) total design criteria (both screening and detail types) and group into several major categories.

5. Relate the applicable design criteria of Step 4 to components and their design environments and their material types. Assign priorities to evaluation criteria.

6. Identify present evaluation test techniques used and note shortcomings, limitations, or problems.

7. Recommend needed new or improved evaluation techniques and relate to component and material type.

8. Discuss trade-off factors and their relative importance pertinent to specific components.

9. Recommend trade-off approaches for particular classes of components and materials.

10. Recommend approaches for relative scope and timing of:
    a. Screening and detail evaluation.
    b. Trade-off studies.
    c. Evaluation techniques development.
    d. Detail design data generation as they relate to component types and vehicles or devices.

As a result of the meeting of the ad hoc Committee, MAB Report 225-M, "Materials Evaluation Techniques," was prepared. This report expanded upon the steps listed above and recommended establishment of an MAB Committee on Materials Evaluation Techniques. Formation of the Committee was authorized by the Department of Defense on January 27, 1967 (Appendix C).

The first meeting of the Committee was held March 1, 1967. MAB-225-M was reviewed for the benefit of those who had not been on the ad hoc Committee. It was pointed out that while MAB-225-M was aerospace-oriented, it was the intention of the Committee to study Army and Navy materials evaluation problems also. Assignments were made to develop presentations concerning Steps 1, 2, and 3 for review at the next Committee meeting. A dual effort was also discussed because some of the members felt we might be usefully guided by some design case histories which would demonstrate the relation of materials evaluation to the design process. Accordingly, assignments were made for case histories dealing with (1) a heat protection panel for a reentry vehicle, (2) a rocket nozzle, and (3) cryogenic booster tankage. Another assignment was made to survey material test techniques in terms of structural performance.

At the second meeting of the full Committee, the information relating to Steps 1, 2, and 3 was reviewed. A number of different formats for data presentation were considered; no scheme for organizing material property data in order to relate them to materials evaluation problems was found. The case history assignments were reviewed, and showed promise of providing a useful pattern of commonality if an adequate number of carefully selected case histories were available. A review of the three case histories which were available suggested establishment of a work sheet which would, among other things, force out:

a. those material evaluation tests needed for selection,

b. those material evaluation tests needed for design, and

c. comments about the adequacy of test techniques.

Assignments were made for ten additional case histories and the ground rules for use of the work sheets were discussed.

At the third meeting most of the case history assignments were completed. A review of the case histories as compiled did not reveal any clear pattern which could lead to a materials evaluation system. It was evident, however, that if case histories were to be useful, they would have to be recorded under a rigid system of discipline. Our basic problem seemed to be one of organizing the data. A proposal was made to organize the data into matrices that would permit the use of machine computation techniques for storage, retrieval, and analysis. The rudiments of a matrix system were discussed. We also discussed the types of information which the matrix system could be expected to supply. This later proved to be a significant step in that it focused the attention of the Committee upon our goals. Assignments were made for development of the matrices. Those who had prepared case histories were asked to enter their case histories into the matrices.

The fourth meeting marked a turning point in Committee activity. The matrices which had been developed related:

a. subsystems and subsystem components,

b. components and environments,

c. components and material evaluation test-screening,

d. components and material evaluation tests-selection, and

e. components and material evaluation tests-design data.

All entries were coded to facilitate eventual machine computation. When the information from the case histories was entered in the matrices, it appeared that if we had sufficient case histories we could completely fill the matrices. This realization came as a shock because such an eventuality would seem to render the system useless. Some of the Committee argued that we needed still more rigid discipline in our approach to the matrix. Others on the Committee were interested in studying failure analysis as a means of developing materials evaluation criteria. Still others were interested in studying test techniques. On the second day of the meeting, the Committee agreed to divide itself into three groups dealing with matrix development, failure analysis, and test techniques. This move had the effect of allowing the Committee to concentrate its efforts. After meeting separately, the three groups got together to discuss their views and their respective assignments.

The Matrix group reported enthusiastically that they felt the matrix approach could be modified so that it would answer at least 40% of the questions posed at the third meeting. This group agreed to meet in advance of the next Committee meeting. The Failure Analysis group felt that the analysis of failures could lead us to a pinpointing of deficiencies in the present system of material evaluation techniques. They agreed to develop an outline to demonstrate their reasoning. The Test Techniques group did not undertake any specific assignments.

At the fifth meeting, the Matrix group advised that they wished to limit their approach to the consideration of screening properties only. A definition of screening properties was agreed upon as was a set of rules for coding of data. The Failure Analysis group studied those material parameters which influence failure modes. It was felt that with such knowledge testing for the avoidance of failure might be simplified or shortened. There was much discussion about the means for incorporating the failure analysis approach into the matrix system, but nothing was agreed upon. No additional progress was ever made with the failure analysis approach because of absences of members of this group and because of

concentration on the matrix approach at subsequent meetings. On the basis of discussions at this fifth meeting, the Matrix group agreed to:

a. Modify the matrices and distribute them to the Committee,

b. Recast the case histories in a new format,

c. Meet well in advance of the next Committee meeting, and

d. Prepare a formal presentation for the next meeting.

At the sixth meeting, the hard work of the Matrix group set the stage for some positive accomplishments. The case histories had been recast in a new format which tended to force compliance with the discipline that had been established. Definitions of screening, selection, and design data properties were adopted. It was decided that the next logical step was to prepare a demonstration of the matrix system. Assignments were made for twelve additional case histories, which, it was felt, would broaden the scope of the applications being considered to demonstrate the system. One of the members volunteered to perform the lengthy task of programming so that at our final meeting we could have a demonstration of the system. The purpose of the demonstration was to show the usefulness of the system even though the number of case histories which had been put into the system was small.

Also at the sixth meeting there was a general discussion of the adequacy of various test techniques. This subject had been touched upon at several meetings without any specific action being taken. One of the members agreed to make a presentation on this subject at the final meeting. Appendix A of this report deals with this subject.

The seventh and final meeting was devoted to a very complete description of the mechanics of computerizing the matrix approach and a demonstration of the utility of the system. The demonstration was performed on the NAS IBM 360 computer installation using tapes and cards that were prepared in advance of the meeting. Several prepared questions were asked of the computer as well as some impromptu ones. Successful operation of the system was demonstrated.

UNCLASSIFIED
Security Classification

| DOCUMENT CONTROL DATA - R & D | | |
|---|---|---|
| *(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)* | | |
| 1. ORIGINATING ACTIVITY (Corporate author) National Materials Advisory Board, National Research Council, National Academy of Sciences-National Academy of Engineering, Washington, D. C. | | 2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED<br>2b. GROUP |
| 3. REPORT TITLE AN APPROACH FOR SYSTEMATIC EVALUATION OF MATERIALS FOR STRUCTURAL APPLICATION | | |
| 4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Final Report | | |
| 5. AUTHOR(S) (First name, middle initial, last name) COMMITTEE ON MATERIALS EVALUATION TECHNIQUES, National Materials Advisory Board, National Research Council | | |
| 6. REPORT DATE January 1970 | 7a. TOTAL NO. OF PAGES 53 | 7b. NO. OF REFS 2 |
| 8a. CONTRACT OR GRANT NO. DA-49-083 OSA-3131<br>b. PROJECT NO.<br>c.<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S) NMAB-246<br>9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) None | |
| 10. DISTRIBUTION STATEMENT Distribution of this document is unlimited. | | |
| 11. SUPPLEMENTARY NOTES None | 12. SPONSORING MILITARY ACTIVITY ODDR&E, The Pentagon Washington, D. C. | |

13. ABSTRACT

An approach is discussed which will enable the Services, the producers and materials engineers to decide upon the type of material evaluation tests which need to be performed for the purposes of obtaining screening, selection and design data. The necessary tests are indicated by a system which takes into account the system, vehicle, component, environment, and operational criteria. The system is based upon the preparation of a large number of applications case histories, the data from which must be recorded according to a rigid format. The compilation of the case histories makes up what is called the Applications Analysis Data Bank. The system can be coded so that the case history data can be computer-analyzed to answer a number of pertinent questions for which answers are not easily obtainable at present. A complete materials evaluation system will consist of three data banks: (1) Applications Analysis, (2) Material Properties (these now exist), and (3) Material Evaluation Techniques. Examples are shown to demonstrate the workings of the proposed system and the many types of questions which can be answered. The necessary steps for the further development of the system are recommended.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

UNCLASSIFIED
Security Classification

**THE NATIONAL ACADEMY OF SCIENCES** is a private, honorary organization of more than 700 scientists and engineers elected on the basis of outstanding contributions to knowledge. Established by a Congressional Act of Incorporation signed by Abraham Lincoln on March 3, 1863, and supported by private and public funds, the Academy works to further science and its use for the general welfare by bringing together the most qualified individuals to deal with scientific and technological problems of broad significance.

Under the terms of its Congressional charter, the Academy is also called upon to act as official—yet independent—advisor to the Federal Government in any matter of science and technology. This provision accounts for the close ties that have always existed between the Academy and the Government, although the Academy is not a governmental agency and its activities are not limited to those on behalf of the Government.

**THE NATIONAL ACADEMY OF ENGINEERING** was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

**THE NATIONAL RESEARCH COUNCIL** was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to enable the broad community of U. S. scientists and engineers to associate their efforts with the limited membership of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial and governmental organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities.

Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

**THE DIVISION OF ENGINEERING** is one of the eight major Divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

**THE NATIONAL MATERIALS ADVISORY BOARD** is a unit of the Division of Engineering of the National Research Council. Organized in 1951 as the Metallurgical Advisory Board, through a series of changes and expansion of scope, it became the Materials Advisory Board and, in January 1969, the National Materials Advisory Board. In consonance with the scope of the two Academies, the general purpose of the Board is the advancement of materials science and engineering, in the national interest. The Board fulfills its purpose by: providing advice and assistance, on request, to government agencies and to private organizations on matters of materials science and technology affecting the national interest; focusing attention on the materials aspects of national problems and opportunities, both technical and nontechnical in nature; and making appropriate recommendations as to the solution of such problems and the exploitation of these opportunities; performing studies and critical analyses on materials problems of a national scope, recommending approaches to the solution of these problems, and providing continuing guidance in the implementation of resulting activities; identifying problems in the interactions of materials disciplines with other technical functions, and defining approaches for the effective utilization of materials technologies; cooperating in the development of advanced educational concepts and approaches in the materials disciplines; communicating and disseminating information on Board activities and related national concerns; promoting cooperation with and among the materials-related professional societies; maintaining an awareness of trends and significant advances in materials technology, in order to call attention to opportunities and possible roadblocks, and their implications for other fields, and recognizing and promoting the development and application of advanced concepts in materials and materials processes.